NEUROPSYCHOLOGICAL DEFINITION OF LEARNING: STRATEGIES FOR REWIRING NEURAL NETWORKS

By

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ABSTRACT

For many years, most scientists believed that the physical structure of our brain, and by definition the people we had become, was set after the initial developmental period of early childhood and adolescence. New research in the area of neurology and neuropsychology reveals that our brain is a much more open system than ever thought possible, and that the physical structure of our brain can be changed through the experiences that we have throughout our lives. This article highlights some of the current research which has led to these conclusions, explains how the neuropsychological research affects our views of learning, and provides some concrete recommendations on how teachers can intentionally pursue and affect long-term changes in the thoughts, attitudes, and behaviors of their students.

Keywords: Brain maps, learning, memory, neural networks, neuroplasticity, perception.

INTRODUCTION

For many years, in fact for most of our lifetime, two prevailing theories about the brain have reigned. The first theory was that unlike other cells throughout the rest of our bodies, which reproduce regularly, brain cells, or neurons, do not replicate. The theory held that individuals were born with twice as many neurons as they would ever need. As a child developed, some neurons were used in processing the various stimuli that entered the brain through the senses, whereas other neurons were not used at all because there were no incoming stimuli to activate them and connect them to other neurons. A common application of this theory is understanding the ability or inability to hear certain tones evidenced in other languages or musical instruments. If we were not exposed to them during the critical period of auditory development, the theory states, then the neurons that could be employed to "recognize" these sounds atrophied. These unused neurons, then, died off and were washed away by the glial cells and cerebrospinal fluid, making it impossible for us to ever gain the ability to hear these sounds. Research is now demonstrating that neurons can be replicated in older brains, as well as in prenatal brains.

This leads to the second prevailing theory, which is probably even considered "common sense" knowledge because of its pervasiveness; after a period of learning and structural brain development occuring from infancy, through childhood, and into adolescence, the structure of the brain was firmly established and the people we had become for better or for worse could not be changed. We were stuck with who we were. According to Nobel Laureate and memory researcher Eric Kandel, "When I was a medical student in the 1950s, we were taught that the map of the brain . . . was fixed and immutable throughout life" (2003, p. 216).

Current research in the area of neuroplasticity, also described as cortical plasticity or brain re-mapping, is affecting our understanding of both of these theories. Neuroplasticity refers to the changes that occur in the organization of the brain as a result of experience, and it influences our understanding of who we are and who we can become. A brain system is made of many neuronal pathways, or neurons, that are connected to one another and working together. There is a growing research base providing evidence that changes in our brain maps are possible throughout our lives, and not just confined to the initial period of childhood. Thought patterns, attitudes, and behaviors are all fluid. Those that we find undesirable may be able to be changed, and understanding the way

our brain works, the role of our brain in perception, and methods by which to influence changes in the brain, can contribute to putting off the negatives patterns and putting on the new ones. This research is essential to teachers. The experiences teachers plan for students will have long-term effects and offers encouragement to make their lives different.

Two Elements of Perception

Anytime we have an experience, which is really part of the definition of life itself, there are two elements at work within our brain to help us understand, interpret, and act upon the world around us. The first element is entitled "bottom-up" perception. Bottom-up perception describes how sensory information enters our cognitive system and includes visual, auditory, olfactory, sensory, and taste sensations. For example, the experience of "sight" is brought into our brains through light reflected-off an items within the visual sphere. Specially designed neurons, or brain cells, in the eyes turn the various levels of light into electrical signals that are passed along optical nerves to the occipital lobe in the posterior/back of the brain where the electrical signals are interpreted, which bring us to the second element of perception, "top-down" processing.

Top-down processing takes the incoming electrical signals and works to interpret them in numerous ways, one of which is to find comparisons between this particular pattern of electrical stimulation and other patterns experienced before. This interpretive matching, then, provides information to the systems as, whether this visual stimuli is something to be sought out and pursued, something to be afraid of, or something new that should be cautiously investigated out of a sense of curiosity. These interpretations occur throughout the brain but most often in areas known as "association areas." Bottom-up perception uses sensory images to construct concepts of the world around us, and involves analyzing and categorizing incoming data and sending the appropriate electrical signals to the correct areas of the cortex for processing. However, the analysis and categorization cannot take place without the concurrent process of top-down perception. In top-down perception, the individual's previously constructed attitudes/beliefs are brought to bear on the incoming data. For teachers, there is a need to acknowledge that students are bringing with them thought patterns, attitudes, and previous understandings that are physically expressed in their brain maps, and they may influence the way incoming information is interpreted.

These neural reactions can also make mistakes. For instance, an individual who has experienced previous failure at a task may approach the same, or a similar task, with a fearful attitude and a belief that failure is unavoidable. This attitude in and of itself may lead to a crippling inhibition or inevitable failure. The key to successful learning, then, is to rewire the neural networks so the material structure of our brain, and the attitudes and thoughts which accompany this structural processing system, does not misinterpret new incoming experiences. But, the question arises, is it possible to rewire the brain as an adult, or, are we left to muddle throughout life with the brain that has developed in childhood?

Neurological Research Developments

In the 1930s, Dr. Wilder Penfield began experimenting with the development of "brain maps," finding where in the brain different parts of the body were represented and the activities of those parts processed. Penfield's area of expertise was in working with individuals who had epilepsy. In an effort to be as exact as possible and reduce the side-effects of the surgery, Penfield would open the skull to expose the brain and then stimulate the brain with electrical probes while the patients were conscious on the operating table (under only local anesthesia), and observe their responses. This technique enabled him to begin developing "brain maps," or correlations between incoming sensory information and areas of the brain responsible for processing and interpreting the stimuli (Penfield, W. & Rasmussen, T., 1950). These brain maps are still in use today, largely unaltered. In addition to mapping the sensory and motor cortices of the brain, Penfield also was able to identify lobes of the brain associated with long-lost childhood memories or dreamlike scenes, which implied that higher mental activities were also mapped in the brain. The work of Penfield led most scientists to believe that human brain

was comprised of specialized areas designated far specific functions, with one area never being able to do the wark of another. Because scientists thought that the brain cauld nat change, they assumed that these mental maps were fixed, immutable, and universal across all people.

Michael Merzenich, however, discovered that these brain maps are neither immutable within a single brain nar universal but vary fram persan ta persan. In a series of experiments, he demonstrated that our brain maps change depending upon what we do over the course of aur lives (Merzenich, M.M., Kaas, J.H., Wall, J., Nelsan, R.J., Sur, M., & Felleman, D., 1983), but it took another decade or more for the scientific community to embrace this research (Kaas, J.H., Krubitzer, L.A., China, Y.M., Langstan, A.L., Palley, E.H., & Blair, N., 1990; Buanamana, D.V. & Merzenich, M.M., 1998). These changes were not measured in large sections or scopes, as Penfield did, but very small changes - a few neurans at a time. Because af advances in technology, this research is possible. Dr. Merzenich used microelectrodes, which are so small and sensitive that they can be inserted autside ar beside a single neuran and can detect when that neuran fires aff its electrical signal to other neurons. This invention allowed neuroscientists to decode the communication of neurans, af which the adult human brain has approximately 100 billion. Merzenich and Jon Kaas (1983) conducted an experiment where one of the three sensary nerves af the hand was cut in an adult mankey, and the brain areas, which are thaught ta be assaciated with interpreting the input were examined. Just as expected, when the area of the hand which had had its sensary nerve cut was straked, the associated part af the brain recorded no activity, which made sense since there was no nerve left to send incoming information to the brain. Hawever, what was mare interesting was that when they straked other areas of the hand, the area of the brain associated with the median part of the hand also was activated. This experiment demonstrated two things: (i) in an adult brain, when input fram the enviranment staps coming in, the area of the brain associated with it will no longer process that input, and (ii) the area of the brain ance assaciated with this enviranmental input will be used by other nerves that are brimming with electrical activity and searching for unused brain map space to process their input. Accarding ta Narman Daidge, "There is an endless war af nerves gaing an inside each af aur brains. If we stop exercising our mental skills, we do not just forget them; the brain map space for thase skills is turned aver ta the skills we practice instead" (2007, p. 59).

Araund the time that Merzenich was canducting his research, and using the same technology of microelectrodes, David Hubel and Torsten Wiesel discavered that the brain in the very young age is "plastic," ar able ta change. They experimented with kittens by sewing shut one of the kittens' eyes during the critical period of visual development in the brain. One of their questians was whether ar nat the brain wauld develap normally without the outside stimulatian or experience. It did not develop normally, but what was even more interesting in this experiment was that the part of the brain narmally cammitted to vision from that eye had nat been inactive, but instead had begun processing the electrical input coming from the open eye. The brain had found a way ta "rewire" itself, cammitting sectians that were ance thought to be identified with one type of processing and changing its function when the outside input or experience was absent. Hubel and Wiesel received the Nabel Prize far their wark, but they still believed that the adult brain was hard-wired by the end of infancy and changes to the brain only occurred during the develapmental periads af childhaad and early adolescence, known as "critical periods".

One impartant cancept that was gained during this time, and that still holds true, is that in order for the brain to develop, environmental stimuli, or experiences are necessary. Just as with the kitten's eye, if the stimulus fram the environment is not present, the part of the brain that interprets this and "understands" this incoming information fram the electrical firing af the neurans, will nat develop, with the end result being perceived blindness, even though all of the neurons are working properly. The brain will have had no opportunity to learn how to interpret this incaming stimuli. These critical periads are essential far

healthy development, and researchers believed that because the brain was immutable in adulthood, they would shape us for the rest of our lives.

Another Nobel prize winner, Eric Kandel, was the first to begin discovering that as we learn, our individual neurons alter their structure (Kandel, 2003). Using research with the Aplysia snail, because of its large nerve and limited numbers of neurons, Kandel, together with James Schwartz, worked for better understanding of the molecules involved in forming long-term memory. Kandel and Schwartz discovered that the brain is plastic, meaning that it does change with each new learning experience that we have and that this occurs throughout our lifetime. They also found that there were specific methods by which the material structure of our brains could be altered for either a short-term or long-term ways that the connections could be strengthened and become almost automatic responses, and moved us toward an understanding of "learning" to come to be defined as neurological changes in the material structure of our brain. The key to successful learning, then, is to rewire the neural networks. Because the profession of teaching is all about student learning, developing strategic awareness of the role of neuroplasticity in learning is an important pedagogical skill.

Recommendations

There are myriad ways in which this neurological research can influence the way we view learning and behavior. The author has listed a few in this article to help the reader to take this knowledge and apply it much more specifically to his/her world.

1. Pay attention:

Unlike the critical periods of learning and brain wiring that occur during the early stages of development in childhood adolescence, students need to pay close attention in order to affect long-term plastic change. In preschool children, there are about 50% more neurons than in school-aged children and youth and greater opportunities for connections. At the end of adolescence, the neurons that are not connecting and firing on a regular basis are pruned away and die off, a classic case of "use it or lose it." Therefore, greater intentionality needs to be evidenced as students get older in order for learning to occur. In numerous experiments, Merzenich found that lasting plastic changes in the brain only occurred when his monkeys were paying close attention. When they were completing tasks automatically, unthinking, or being asked to multitask, change occurred in the brain maps, but this change did not endure (Kilgard, M.P. & Merzenich, M.M., 1998). Our societies tend to praise individuals who can multi-task or divide their attention, but this is not a desirable trait when learning new knowledge, skills, or thought and behavioral patterns. When asking students to learn a new task, or a new thought or behavioral pattern, decrease the amount of attention that is divided during the learning period. Teachers who can successfully decrease the number of interruptions throughout the day or various tasks on which students are working and increase the level of curiosity and interest in the material at hand will have greater gains in long-term student learning than those who do not.

2. Space learning experiences over time:

In his research with the Aplysia snail, Nobel Laureate Eric Kandel attempted to locate "learning" in the smallest grouping of neurons possible. He found that when learning sessions were spaced out in smaller increments over time, the residual long-term effects were more pronounced than when learning session were spread over larger amounts of time in short spaces. Roughly translated, this means that shorter sessions each day over a three-week period are more effective than intensive learning sessions that last for several hours over two days, commonly called "cramming". Thinking through how we expect students to learn in the everyday environment can influence how well individuals retain the knowledge, skills, and/or thought patterns over time.

3. Monitor associations:

"Neurons that fire together wire together" is a commonly used neurological phrase. In 1949, Canadian behavioral psychologist Donald O. Hebb proposed that when two neurons fire at the same time repeatedly, chemical changes occur in both, so that the two tend to connect

more strongly. When we have experiences that occur at the same time as other experiences, they both become associated. Therefore, when we are asked to complete a given task, such as giving a speech in front of our classmates, and some of the students laugh at us, these two experiences wire together in our brains and an association occurs between giving a speech and feelings of humility and embarrassment. The next time when the student is asked to give a speech, he may have some hesitations because of previous associations. In order to overcome these hesitations, the student needs to form new associations within his brain. This may mean giving a speech for no audience for a specified time, and then, when the student begins to feel more comfortable, introducing only one person as an audience. Gradually, gaining experiences where new associations are formed between speech giving and accolades, or at least recognized competence, will result in a new structure of neural networks that are wired together and will fire together automatically, unless future experiences alter these structures. It is possible for the brain to rewire, so that giving speeches are now associated with feelings of competence and excitement.

4. Understand the need for unlearning:

The neuroscience of "unlearning" is fairly new. Because of neural plasticity, when neural networks are created, they become efficient, self-sustaining, and robust, as well as difficult to abolish. Weakening this process is just as plastic, or mutable, as learning, or strengthening neural networks, and takes intentionality. If we only focused upon developing new neural networks and not on abolishing older, undesirable ones, our brain would become overloaded and saturated. One of the ways for "unlearning" to occur is through abstinence: stopping fully the activity or thought processes that we want to abolish and thereby stopping the electrical activity that flows through that neural network. Through dis-use over time, the network will weaken and be subject to displacement with other patterns that are more desirable and robust. Teachers need to understand this process and identify the pattern(s) that they want to eradicate, and then take the next step of helping students abstain from these patterns.

The importance in this case is resistance to the greatest extent possible. Sometimes, thought patterns in the form of attitudes, opinions or feelings are upon us and are being entertained by us without apparent conscious attention. When the attitude enters consciousness, or the automatic activity is realized, the individual needs to refuse to continue in that pattern and resist it to the greatest degree possible. This will become easier over time as the neural network supporting it weakens. To best help students "unlearn" specific thought patterns and/or behaviors, teachers might choose to discuss with the student individually to identify the undesirable patterns and then serve as a reminder to the student whenever she is exhibiting these patterns and tell her to stop. Through the continuous efforts of both teacher and student together, the neural network committed to those patterns will eventually atrophy and the neural space will be taken over by other habits that are intentionally being developed.

Schwartz (1996) recommends to his Obsessive-Compulsive Disorder patients that they intentionally replace thoughts and feelings of worry with pleasurable thoughts instead that will release dopamine into their brains and thereby strengthen the connection of pleasurable thoughts while at the same time weaken the connection with the undesirable concern or worry. This intentional shift, which initially takes work, will eventually, over time, become more automatic until our thought processes naturally flow and we are unconscious of a different state of attitude or practice.

5. Perfect Practice:

Our brains have a limited amount of physical space. Those experiences that occur frequently command more of the neurological space in the brain as opposed to experiences that occur rarely. Doidge (2007) explains that when we ask about how frequently we need to practice French, or guitar, we are really asking the question of competitive neural plasticity: how often I need to practice this in order to guarantee that the brain space won't be taken over by another activity. Competitive neural

plasticity also explains why our bad habits are so difficult to break or "unlearn." Most of us think of 'the brain' as a container and 'learning' as putting something into it. When we try to break a bad habit, we think the solution is to put something new into the container. But when we learn a bad habit, it takes over a brain map or a section of cognitive real estate, and each time we repeat it, it claims more control of that map and prevents the use of that space for "good" habits. That is why "unlearning" is often too harder than learning, and why early childhood education is so important-it is best to get it right early, before the "bad habit" gets a competitive advantage. Working with students to continue practicing those critical thinking skills and behavioral patterns that we are trying to teach will assist their brains in establishing robust neural networks that will be difficult to eradicate and the easiest neural pathway for future thought patterns to follow.

6. Reward Success:

B.F. Skinner's work in operant conditioning proposes a reward structure, or reinforcements, to increase the likelihood that certain behaviors will be repeated and punishments to decrease the likelihood of the repetition of other behaviors. There is support for this theory in neuropsychological research. When individuals are rewarded, the brain releases a chemical called dopamine, sometimes referred to as the pleasure chemical. The same surge of dopamine that causes this feeling of competence or thrill also consolidates neuronal connections responsible for behaviors that led us to accomplish our goal. Neuronal connections that are not rewarded do not have the accompanying dopamine and therefore have less of a chemical bond. Because plasticity is competitive there is only so much space in the brain those connections which are stronger will continue to hold the space in the brain whereas weaker connections are at risk for being taken over by newer experiences which may bring with them dopamine. For teachers, rewarding positive thinking and behavioral patterns increases the likelihood they will be repeated psychologically and neurologically.

Conclusion

There is still much research to be done. First, it is unknown exactly how thoughts change our brain structure, and the realm of understanding consciousness, or the soul, is of key interest to many. Second, the line between the mind, the brain, and the soul is increasingly becoming a dotted line, and seeking rightly understanding of the connections and distinctives of each of these elements is one of the basic questions of human nature. Third, how much of our brains can be rewired and how much of our baggage is here to stay, regardless of learning experiences, remains a question yet to be answered. What we do know with some degree of certainty is that our thoughts change the material structure of our brain and by intentionally manipulating our thoughts, attitudes, and behaviors putting off the old and putting on the new we can change the physical maps of our brains and then in a cyclical pattern, influence our perceptions of our life experiences and our world which will affect the material structure of our brain in turn. Change will not occur overnight because neuroplastic change takes time, but it does lay the groundwork for changing by exercising the brain in a new way and establishing new neural networks that will guide our cognitive perceptions and as an extension, will guide our thoughts, attitudes, and behaviors. Using some of the concrete strategies recommended in this article, along with other methods that neuroscientific research discovers in the future, will assist teachers in contributing to the development of their students into people, communities, and societies which they most greatly value and desire. The brain is a much more open system than we have ever thought possible and was designed to survive in a changing world by the ability to change itself.

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